NASA GRC CRYOGENIC SEAL TEST RIG CAPABILITY

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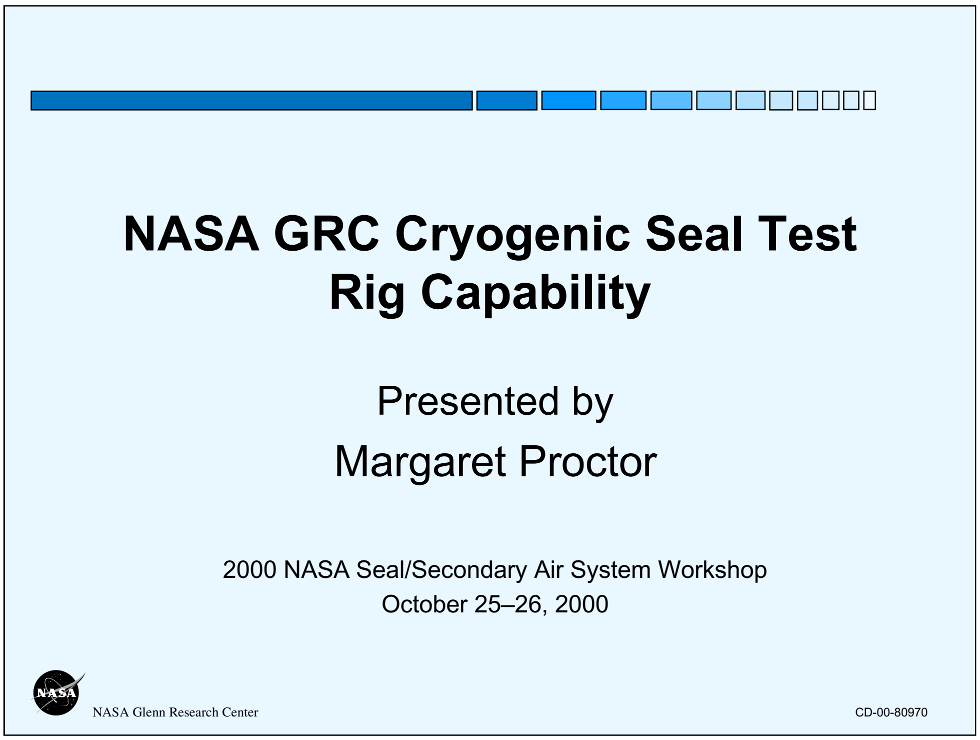


It has been about 6 years since any cryogenic seal tests were run at NASA GRC. The Cryogenic Components Lab, where the cryogenic seal test rigs are located, has been shutdown due to the impending expansion of the Cleveland Hopkins International Airport. The current plan is to move the Cryogenic Components Lab (CCL), Cells 1 and 2 to NASA Plumbrook in Sandusky, Ohio. The purpose of this presentation is to inform the seal community of the cryogenic seal test rig capabilities available at NASA GRC for planning of future programs.

Cryogenic Seal Test Rigs at NASA GRC

1. **Lox Seal Test Rig**

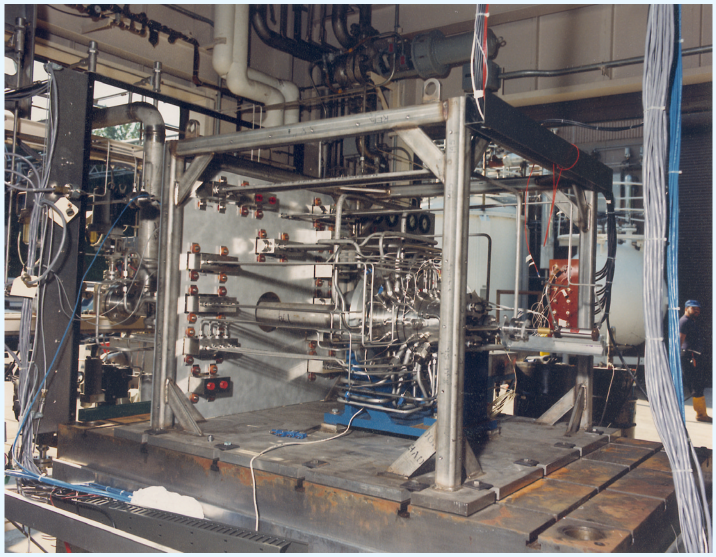
   Designed and built by Mechanical Technology Inc. under NASA Contract NAS3-23260 to test seals for liquid oxygen turbopumps.

2. **Cryogenic Brush Seal Test Rig**

   - **Originally designed and built by Rocketdyne under NASA contract to test low thrust pumps.**
   - **Modified by NASA to test brush seals in LN_2 and LH_2.**

Two test rigs are available to test cryogenic seals. The Lox Seal Test Rig was designed and built by Mechanical Technology, Inc. under a NASA contract to test seals for liquid oxygen turbopumps. The Cryogenic Brush Seal Test Rig was originally designed and built by Rocketdyne under a NASA contract to test low thrust pumps. NASA then modified the rig to test brush seals in liquid nitrogen and liquid hydrogen.

Lox Seal Test Rig



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This photograph shows the Lox Seal Test Rig as it was installed in Stand C at the Rocket Engine Test Facility. Some initial testing was conducted. Due to conflicts with other test stands at the Rocket Engine Test Facility, it was decided to move the Lox Seal Test Rig to the Cryogenic Components Lab, Cell 1 (CCL-1). About half way through the facility build-up at CCL-1, funding resources were cut. The Lox Seal Test Rig components are stored in cabinets.

Lox Seal Test Rig Capabilities

- 50-mm and 20-mm seal hardware
- Face seal or ring seals
- 750-psi LN_2 or Lox seal supply
- 200-psi GHe seal supply
- 100,000-rpm maximum shaft speed (depending on seal)
- 100-hp GN_2 turbine drive, overhung, radial inflow
- Axial vibration can be imposed via thrust bearing control

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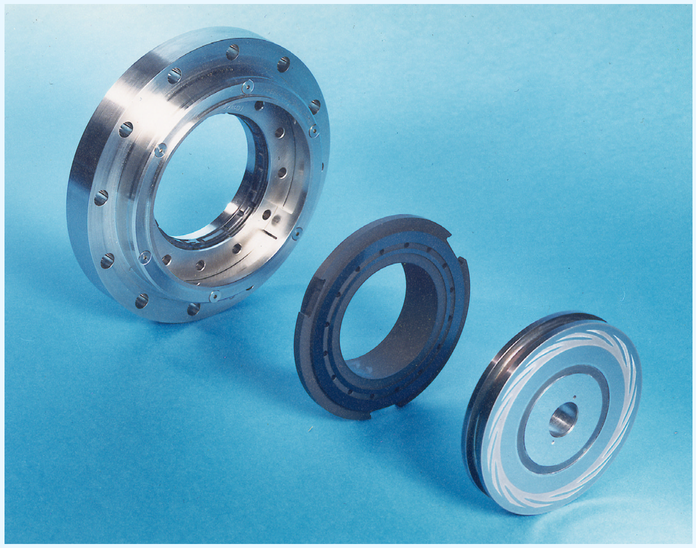
The Lox Seal Test Rig was designed to test both 50-mm and 20-mm seal hardware. These two sizes are representative of the shaft sizes used in turbopumps for launch vehicles and orbital transfer vehicles, respectively. Both face seals and ring seals can be tested. Lox spiral-grooved face seals and Rayleigh-step, helium-buffered ring seals were designed and fabricated for testing in this rig. The rig and test facility was designed for 750-psi liquid nitrogen or liquid oxygen seal supply. This high pressure LN2 or Lox also supplies the hydrostatic bearings. No testing has been done with lox. When testing the helium buffer seal, up to 200 psi gaseous helium can be supplied to the seal and liquid nitrogen is supplied to the hydrostatic bearings. Shaft speeds up to 100,000 rpm can be attained depending on which seal rotor is being used. The maximum shaft speed is 100,000 rpm for 20-mm Lox and helium seals; 56,000 rpm for 50-mm Lox seal and 70,000 rpm for 50-mm helium seal. The rig is powered by an overhung, radial inflow, 100-hp gaseous nitrogen turbine drive. Axial vibrations can be imposed by controlling the thrust bearing. The rig was designed to provide axial shaft vibrations up to +/- 0.005 inch with a frequency of 10 Hz.

Lox Spiral Groove Face Seal



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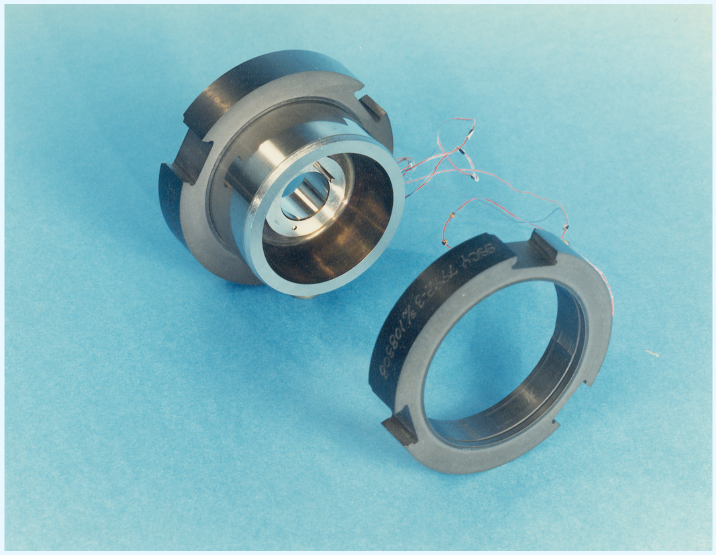
This photograph of the Lox Spiral Groove Face Seal shows a stationary carbon ring (center) and the spiral groove rotor (right). The carbon ring is held in the seal holder (left).

Raleigh-Step Helium Buffer Seal



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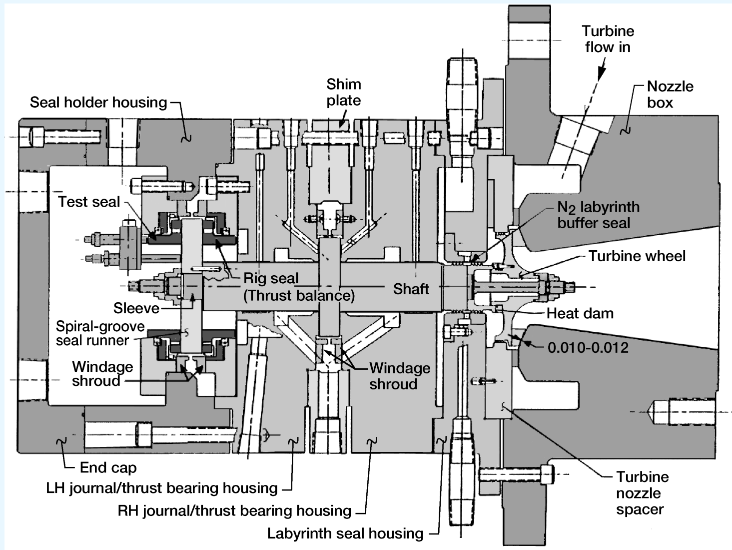
The Raleigh-step Helium Buffer Seal is comprised of a rotor and two carbon rings. Helium is supplied to a space between the two carbon rings. Helium then leaks axially through the gap between the carbon rings and the rotor. On the inner diameter of each carbon ring are four shallow pockets, which generate a hydrodynamic lifting force during shaft rotation. This lifting force prevents the seal from contacting the rotor and wearing the seal.

Lox Seal Test Rig



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This cross section of the Lox Seal Test Rig has a pair of face seals installed on either side of the spiral groove seal runner mounted on the left end of the shaft. Lox or LN2 is supplied to the outer diameter of the seal runner. The Lox or LN2 leaks radially inward through the seal. The inboard seal is a slave seal to balance axial loads on the shaft. Its leakage flow enters a drain in the LH journal/thrust bearing housing. The test seal is the outboard seal and its leakage exits through the end cap. Two proximity probes are shown. One measures the axial motion of the test seal, the other measures the motion of the seal runner. The difference between these two measurements provides the clearance. This approach to tracking the seal clearance is not very accurate due to thermal gradients. Therefore, proximity probes have been flush mounted in the test seal to directly measure the clearance between the seal and the seal runner. The shaft is supported by two hydrostatic journal bearings which are supplied with either Lox or LN2. A hydrostatic thrust bearing located approximately in the middle of the shaft controls axial shaft motion. Gaseous nitrogen drives the radial inflow turbine mounted on the right end of the shaft. A GN2 labyrinth buffer seal keeps LN2 from entering the turbine cavity.

Lox Seal Test Rig During Test

This photograph shows the Lox Seal Test Rig during a test.

Cryogenic Brush Seal Test Rig Capabilities

- 2-in.-diameter bore seals
- 5 brushes at one time - use long, low speed runner
  maximum speed 40,000 rpm
- 1 brush at a time - use short, high speed runner
  maximum speed 65,000 rpm
- 800-psig MAWP of rig
- Maximum Delta-P across seal is 300 psi due to balance piston capability
- LH_2 or LN_2
- 14 seal temperature measurement locations
- 14 seal pressure measurement locations
- 3 proximity probes measure rotor orbit

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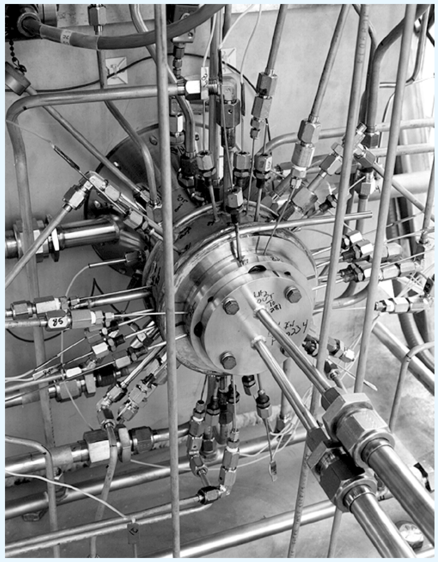
The Cryogenic Brush Seal Test Rig was designed to test 2-inch diameter bore brush seals. Up to five brushes can be tested at one time using a long, low speed seal runner, which has a maximum shaft speed of 40,000 rpm. A short, high speed runner can be used to test at speeds up to 65,000 rpm. With this runner only one brush seal can be tested. Special seal spacers were used to allow pressure and temperature measurements between seals to study staging effects. The rig has a maximum allowable working pressure of 800 psig. However, the maximum pressure drop across the seal that can be attained during rotation is 300 psi due to the balance piston capability. Either liquid hydrogen or liquid nitrogen can be used in this rig. There are fourteen temperature and fourteen pressure measurement locations. Three proximity probes are used to measure the seal runner orbit.

Cryogenic Brush Seal Tester Installation



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This is a photograph of the Cryogenic Brush Seal Tester as it is installed in the Cryogenic Components Lab, Cell 2 (CCL-2) and as viewed from the test seal end of the rig.

Typical Brush Seal

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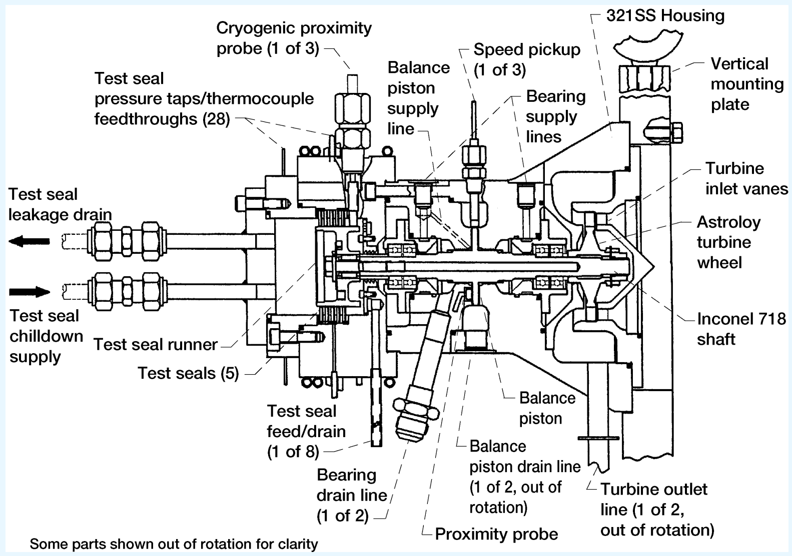
This is a typical brush seal. It is made of a pack of metal wire bristles at an angle to the radius of the inner diameter and sandwiched between an upstream sideplate (visible in photo) and a downstream sideplate (not visible). The bristles are typically 0.002 to 0.003 inch in diameter and flex like a cantilevered beam during shaft growth or excursions.

Cross Section of Cryogenic Brush Seal Tester



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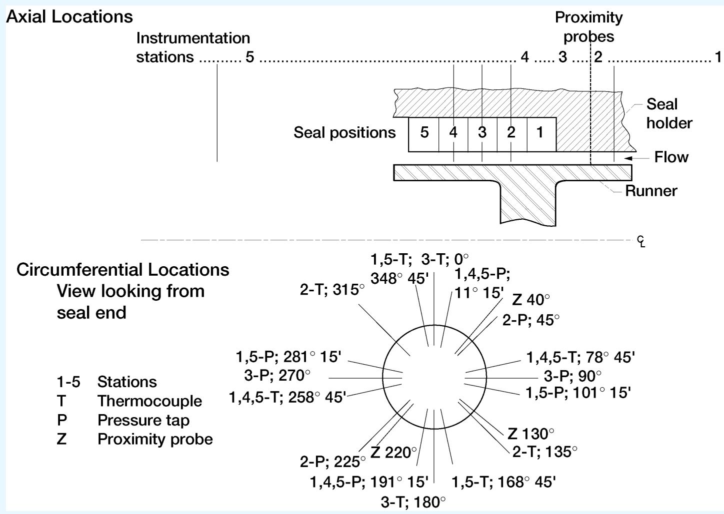
This cross section of the Cryogenic Brush Seal Tester shows the shaft is supported by two pairs of ball bearings. A balance piston is located between these bearings to balance out the axial loads due to the pressure drop across the seal. The rig is driven by a gaseous nitrogen or hydrogen, full-admission, axial-flow turbine depending on the test fluid. The long, low speed seal runner is shown attached to the left end of the shaft. Five test seals are shown. The test fluid (LN2 or LH2) is supplied to the inboard, high-pressure side of the seal runner. It then passes through a perforated plate, which is integral with the test-seal-end labyrinth seal, to steady the flow. In tests where the brush seal leakage was low, it was necessary to bypass some flow out of the seal supply cavity to keep the rig cold enough.

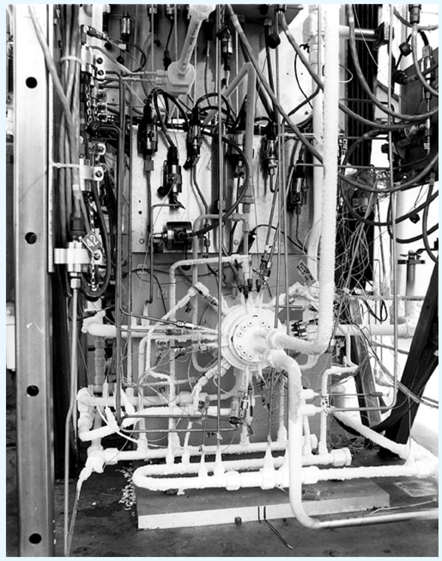
Location of Brush Seal Positions and Instrumentation Stations

Low-Speed Runner Shown



This shows the location of the pressure, temperature, and proximity measurements. Spacers with holes for instrumentation can be put in seal positions 2, 3, and 4 to measure interstage conditions.

Cryogenic Brush Seal Tester During Test



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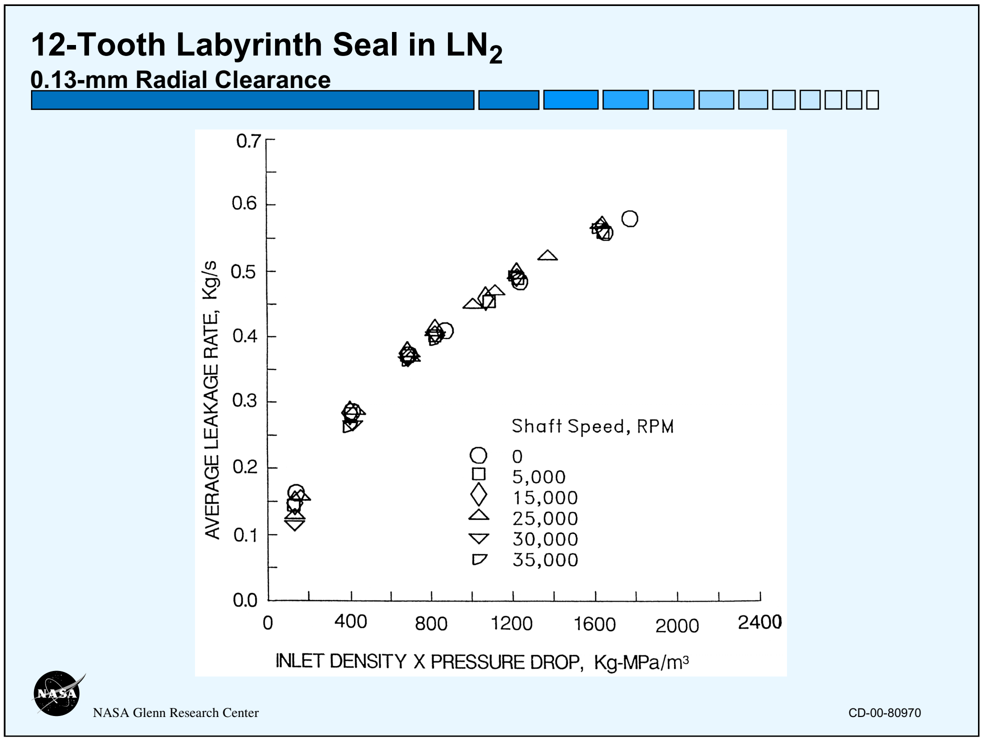
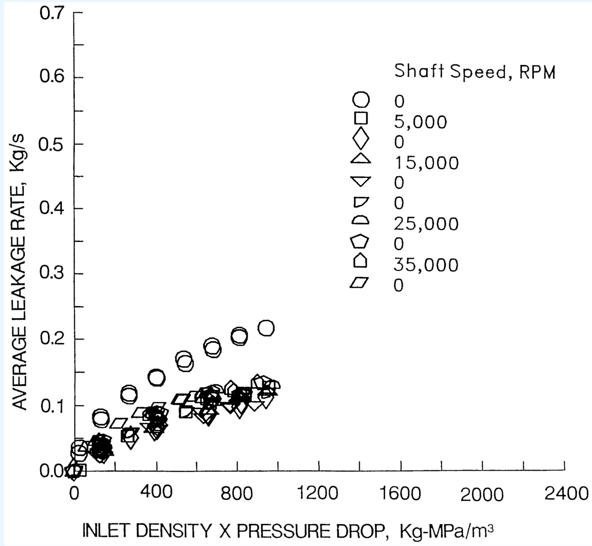
Self-explanatory.



This is a plot of leakage rate vs. inlet density times pressure drop for a 12-tooth labyrinth seal in liquid nitrogen. The seal had a radial clearance of about 0.005 inch.

Single Brush Seal in LN_2 0.11-mm Radial Interference



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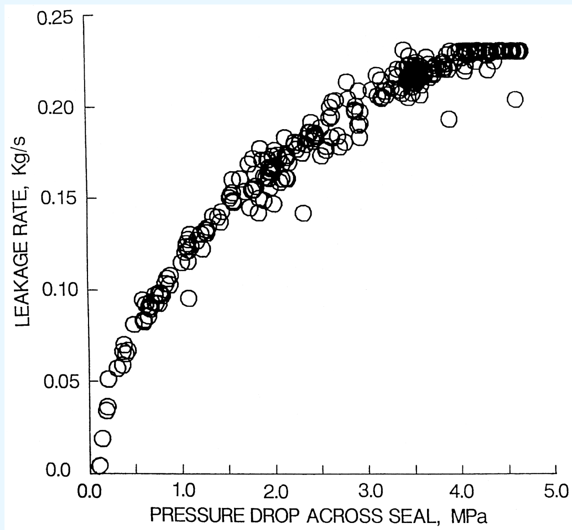
The leakage rate of a single brush seal in liquid nitrogen is about one-half to one-third that of the 12-tooth labyrinth seal with a radial clearance of 0.005 inch. Note that the data shown as circles, taken at 0 rpm, was the first pressurization of the seal. Subsequent data shows a lower leakage rate and indicates that some rotation is needed to fully seat the seal.

Blowout Test of a Single Brush Seal in LN_2 at Zero rpm



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A blowout test was done of a single brush seal in liquid nitrogen at zero rpm. Blowout means that the bristles bend in the axial direction to the point where they no longer contact the shaft. It was anticipated that if blowout were to occur, then the leakage rate would suddenly increase. As can be seen, there was no indication of blowout at pressure drops across the seal up to 3.8 Mpa (550 psid). The leveling out of data above 3.8 Mpa is due to the pressure transducers being at their maximum reading limit.

Tribological Performance Summary for LH_2 Brush Seal

35,000 rpm

SEAL RUNNER COATING	ACCUMULATIVE TEST DURATION (min)	ACCUMULATIVE LINEAR SLIDING DISTANCE (Km)	ACCUMULATIVE BRISTLE WEAR (μm)	MAXIMUM RADIAL SEAL RUNNER WEAR (μm)
INCONEL-718 (UNCOATED)	43	213	64	-17 (DEPOSITED)
CrC	51	223	25	6
Cr+TEFLON	28	86	(NEGLIGIBLE)	(NEGLIGIBLE)
ZrO_2	47	222	5	90

65,000 rpm

SEAL RUNNER COATING	ACCUMULATIVE TEST DURATION (min)	ACCUMULATIVE LINEAR SLIDING DISTANCE (Km)	ACCUMULATIVE BRISTLE WEAR (μm)	MAXIMUM RADIAL SEAL RUNNER WEAR (μm)
INCONEL-718 (UNCOATED)	38	300	41	-17 (DEPOSITED)
CrC	58	450	38	20
Cr+TEFLON	66	577	56	12
ZrO_2	48	337	18	85

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Wear testing was done for an uncoated Inconel 718 rotor, a rotor coated with chrome carbide, a rotor coated with chrome carbide and impregnated with Teflon, and a rotor coated with zirconium oxide. Testing was done at both 35,000 rpm and 65,000 rpm. Bristle material was deposited on the uncoated Inconel 718 rotor at both speeds. The zirconium oxide coating had the most wear at both speeds. The chrome carbide coating had small amounts of wear, but the chrome carbide coating impregnated with Teflon had negligible wear at 35,000 rpm and less wear than the chrome carbide alone at 65,000 rpm. The Teflon has a lubricating effect, but does wear away.

For more details see NASA TM 107203, “Wear Characteristics of Three Rotor Coatings for Application to Brush Seals Operating in Liquid Hydrogen,” by James F. Walker and Margaret P. Proctor, 1995.

For more details about the Cryogenic Brush Seal Test Rig, see NASA TP 3536, “Brush Seals for Cryogenic Applications Performance, Stage Effects, and Preliminary Wear Results in LN2 and LH2,” by Margaret P. Proctor, et. al., 1996.